New Research and BMPs in Natural Areas: A Synthesis of the Pollinator Management Symposium from the 44th Natural Areas Conference, October 2017

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FEATURED PAPER

New Research and BMPs in Natural Areas: A Synthesis of the Pollinator Management Symposium from the 44th Natural Areas Conference, October 2017

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INTRODUCTION

Land managers face constant challenges when balancing multiple land use goals that include ensuring that keystone species are protected. As mindful stewards of our natural areas we aim to promote, secure, and enhance our natural landscapes and the species that make them their home. When we focus our efforts on protecting and promoting pollinators as well as the ecosystem services they provide we are met with an additional challenge. Limited resources and guidance are available, the data is patchy, and there is an enormous diversity of species. More than 30,000 bees (Michener 2000), 150,000 butterflies and moths (Grimaldi and Engel 2005), 150,000 flies (Thompson 2006), 12 bats (Medellin et al. 1997), 63 birds (Arizmendi and Ornelas 1990), and over 350,000 other arthropods, primarily beetles (Grimaldi and Engel 2005), visit flowers, transferring pollen and aiding in reproduction. This is compounded by the diversity of ecosystems globally and the sheer number of plant–pollinator interactions that can be expected. Pollinators are directly responsible for the reproduction of 67–96% of flowering plants globally (Ollerton et al. 2011); these flowering plants define our natural landscapes and ecosystems.

When pollinators are considered in management decisions, ecosystem benefits can include increased pollination services and overall support of other key ecosystem services. Evidence of the impact that proactive pollinator management has is most clear and abundant in agricultural systems, where hedgerow and habitat planting translates to increased pollinator occurrence (Shepherd et al. 2003; Kremen et al. 2004; Ricketts et al. 2008) and often benefits crop yields (Klein et al. 2003; Greenleaf and Kremen 2006; Garibaldi et al. 2014). Increasing floral diversity in urban and suburban areas through habitat planting and gardening shows the same positive trend of attracting diverse communities of pollinators (Hernandez et al. 2009; Wojcik and McBride 2012). Less evidence exists for the restoration of natural landscapes; nevertheless, case studies indicate that planting for pollinators (Cane and Love 2016; Tonietto and Larkin 2018) or modifying management practices and seed mixes (Galea et al. 2016; Harmon-Threatt and Chin 2016) indeed results in corresponding positive changes in the pollinator community: more pollinators using the landscape and more plant reproduction as a result.

To address the growing interest and expressed need for pollinator management strategies a special pollinator symposium was held at the 2017 annual meeting of the Natural Areas Association, curated by William Carromero of the US Forest Service and Lisa Smith of the Natural Areas Association. The overarching goal of this symposium was to present new research and the current body of knowledge surrounding pollinator system management to practitioners, giving them the tools to better manage this essential natural resource. Although such an extensive topic can hardly be examined fully in a half-day symposium, the topics presented showed that research is progressing in an effort to fine-tune best management practices across ecosystems. Active research into pollinator management and conservation on natural areas addressed large ungulate grazing and forest management, with a focus on alpine systems. Reviews of research, practices, and programs intended to provide management guidance focused on honeybee pasturing on natural lands, prairie restoration seeding, and managing pollinators in western regions. This synthesis, written by the presenters and participants, recapitulates the symposium with a presentation of research and review findings, and an assessment of key gaps and next steps in topic area. Pollinator management in natural areas is a broad topic. The symposium allowed us a detailed look at a subset of topics, starting the discussion on how we aim to consider pollinators in our land management decisions.

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NATIVE BEES AND LARGE MAMMALS: VERTEBRATE–INVERTEBRATE INTERACTIONS IN RIPARIAN NATURAL AREAS

Presented by Mary Rowland

Grazing is perhaps one of the most common managed land uses in natural landscapes. Its management focuses on both native ungulate species, which provide recreational, socioeconomic, and cultural benefits, and nonnative livestock species, such as cattle (*Bos taurus*) and sheep (*Ovis aries*). Livestock grazing has occurred for well over a century in North America. While it can be well-managed, many gaps remain in our understanding of its impact on the full scope of ecosystem services provided by natural lands and its interaction with native ungulate herbivory. Investigations of how grazing impacts pollinators are beginning to illuminate how grazing-induced changes in floral abundance, plant community composition, plant architecture, and soil characteristics, such as compaction (a key factor for ground-nesting bees), influence pollinator communities (e.g., Carvell 2002; Kruess and Tscharntke 2002b; Vulliamy et al. 2006; Hatfield and LeBuhn 2007; Sjödin 2007; Kearns and Oliveras 2009; Kimoto et al. 2012). There remains, however, very little known about the effects of native ungulate herbivory on pollinators, especially in the United States.

The degree to which strategies for managing ungulates and pollinators in natural areas may conflict with each other is not well understood, especially in sensitive areas such as riparian zones (DeBano et al. 2016). Riparian systems provide key resources to native grazers and are often preferred by livestock, especially during summer when green forage has senesced in upland areas. Significant impacts of livestock grazing in riparian areas have been documented, particularly for cattle in arid ecosystems (Kauffman and Krueger 1984; Belsky et al. 1999). However, herbivory by wild ungulates such as deer (*Odocoileus* spp.) and elk (*Cervus canadensis*) can also affect vegetation in riparian areas (Averett et al. 2017). Riparian systems are often a focus of restoration and management, in recognition of the relatively high biodiversity and ecosystem services these lands provide compared to other systems (Kauffman and Krueger 1984). Riparian areas also often contain species assemblages that differ from upland ecosystems (DeBano et al. 2004). These wetland systems have a history of frequent disturbance and subsequent restoration, and thus often represent a very actively managed landscape type within natural areas.

What is our current state of knowledge of impacts of ungulate grazing on pollinators? Herbivory can impact plant architecture, abundance, growth, diversity, and species composition (Black et al. 2011). Depending on the preferences of the grazing ungulate involved, herbivory can alter potential food resources for pollinators, both by decreasing and, in some cases, increasing biomass and abundance of certain species (Vázquez and Simberloff 2004; Vulliamy et al. 2006).These changes can, in turn, influence the abundance of pollen and nectar available to pollinators, as well as the availability of nesting material and habitat. The physical presence of large mammals in the landscape can also impact soils, including compaction and stability, which can affect habitat quality for ground-nesting bees (Kimoto et al. 2012; Schmalz et al. 2013). A more nuanced impact of grazing is the alteration of microhabitat conditions, including changes in temperature and humidity (DeBano 2006). Both temperature and humidity can impact pollen and nectar availability in plants, as well as the development of bees in some cases.

Given the variety of factors that may be influenced by ungulate grazing, a first step in developing best management practices in riparian areas that consider ungulates and pollinators is to identify areas of shared niche space between these groups. Diet overlap between large herbivores and pollen- and nectar-seeking species, combined with common feeding habitats, create the potential for competition of food resources. At the most fundamental level, grazing removes plant resources that pollinators use (i.e., flowers). However, direct competition may be reduced depending on the timing of herbivory (e.g., pollinators may feed on the plant prior to the grazing event or regrowth may occur after blooming, including additional blooming). Nevertheless, ungulate herbivory can alter the availability of pollen or nectar in a system and understanding the basics of diet overlap among these groups can help managers predict where and when such interactions might occur and their outcomes.

As part of a larger, collaborative project evaluating interactions of ungulate grazing and riparian restoration for salmonids at the Starkey Experimental Forest and Range (Starkey) in northeastern Oregon, a US Forest Service (USFS) and Oregon State University (OSU) research team is exploring how herbivory by large mammals may influence native bees. First, the team conducted a literature review aimed at understanding the potential of dietary overlap among native bees, deer, elk, and cattle, focusing on riparian species recorded along Meadow Creek within Starkey (DeBano et al. 2016). The review revealed that bees may use approximately 30% of plant species present in this riparian area; elk were reported as feeding on 43% of Meadow Creek species, deer were reported feeding on 19%, and cattle on 16%. The relative percentage of species documented in diets of ungulates that were also identified as important to bees was approximately 55% (DeBano et al. 2016). In summary, the literature review showed that ungulate grazers and bees have high potential for dietary overlap, with over half the species found within this riparian area that are believed to be important to bees also known to be consumed by ungulate grazers. Current research is underway to examine the realized resource overlap among these species in the Meadow Creek riparian area by documenting which plants are actually used by bees for nectar and pollen, and by comparing cattle vs. deer and elk impacts on floral resources. Bees make use of a variety of woody and herbaceous plants such as willows and yarrow.

Research Methods and Initial Results

A major goal of the USFS pollinator research at the Meadow Creek site within Starkey is to examine wild ungulate and livestock impacts on floral resources for native bees, partitioning out effects by ungulate type. A series of exclusion experiments within a newly restored riparian area has been in place since 2014 (Averett et al. 2017). Native bees and floral resources were sampled from spring to fall in 2014–2016 along a 14 km reach of Meadow Creek to document flowering species most commonly visited by native bees and the seasonal and spatial dynamics of the bee community, and to quantify how herbivory by deer and elk influences flowering plant communities. (Cattle were not introduced into the system until 2017.) Half of the 12 sampling sites were excluded from native ungulate grazing to provide a comparative baseline to grazed sites. More than 150 species of flowering forbs and shrubs were recorded along Meadow Creek during this time, and plant visitation records of more than 900 bees representing more than 80 species has been documented (Roof et al. 2018).

Initial analyses suggest that floral abundance, quantified by blooming stems, was generally higher in ungrazed sites than in grazed sites, although patterns were highly variable in time and space and across plant species. Because the flowering plant community at Meadow Creek is particularly diverse and site-to-site variability is high, responses to herbivory are complex. However, several individual species focused on thus far suggest that some plant species may be of greater concern relative to ungulate management and native bees. For example, one common dominant flowering species commonly visited by bees, slender cinquefoil (*Potentilla gracilis*), became significantly less dominant in ungulate-grazed sites over time. Some plant species, however, displayed no response to grazing, such as common yarrow (*Achillea millefolium*), while other species showed tendencies to decrease in abundance over time when excluded from grazing.

Management Considerations for Grazing and Pollinators

Both livestock and native ungulates are known to be common ecosystem engineers (Jones et al. 1997). While spatiotemporal patterns of herbivory have varied effects, herbivory's impact on floral communities may have consequences for ecologically significant invertebrates such as native bees. Although Starkey research is ongoing, some guiding principles and concepts are emerging. First, there are key areas of spatial and temporal overlap between ungulate grazing and pollinator usage, and our knowledge of the extent of this overlap is becoming more refined as research progresses. Native ungulates and livestock graze on many of the same species that native bees rely on for pollen and nectar, but the potential for dietary overlap does not necessarily mean competition to the detriment of pollinators, especially if resource use by ungulates and pollinators is spatially and/or temporally separated, if plants are able to compensate for grazing, or if plants respond to grazing with more growth. Research suggests that managers should pay particular attention to flowering species highly preferred as forage by native ungulates and livestock and determine whether those plant species are also preferred floral resources for native pollinators. This may be particularly important for pollinator species of concern that appear to rely heavily on ungulate-preferred plant species, and if temporal and spatial overlap with grazing ungulates is likely. When riparian restoration involves planting of mass-blooming shrubs or forbs that may provide pollen or nectar—or both—for pollinators, short-term exclusion of plantings from herbivory may be beneficial. Future lines of research addressing this topic would benefit restoration ecology in natural areas where pollinator conservation is of interest.

BIOLOGICAL DIVERSITY OF POLLINATORS IN A HIGH-ELEVATION SPRUCE FOREST

Presented by Seth Davis

Forests make up a substantial portion of natural lands in North America and are managed for a variety of objectives including recreation, restoration of natural processes, and timber harvest. Although management activities may alter the structure, function, and composition of forest ecosystems, there is little known about how these shifts may impact native pollinator communities, especially high-elevation forests. There is a general lack of foundational knowledge on the basic biodiversity and abundance of pollinators in alpine systems, which detracts from the ability of practitioners to design forest management applications that meet objectives while simultaneously promoting conservation of pollinator habitat. However, high-elevation forest landscapes in western North America are vast and may serve as valuable refugia for endemic pollinators, especially under continued land use intensification and an expanding wildland–urban interface (Platt 2010). Climate change is also predicted to have a more major impact on high-elevation forest. Accordingly, there is a pressing need to develop an understanding of pollinator communities in alpine forests, and to quantify the factors that may relate to pollinator site occupancy.

Various natural disturbance processes of forest ecosystems have dramatic impacts on the structure of western coniferous forests, particularly fire and bark beetles (Tinkham et al. 2016). These disturbances can significantly alter floral resource availability, which has a corresponding impact on bee pollinators. For example, in fire-adapted forest ecosystems bee richness increases rapidly following fire disturbances but then gradually declines as successional patterns alter floral reward structure (Potts et al. 2003). Similarly, bark beetle outbreaks in European spruce forests are positively correlated with site occupancy of both common and red-listed bees and wasps (Beudert et al. 2015), probably due to the effects of newly created canopy gaps resulting from bark beetle kill. However, anthropogenic disturbances that fragment forest landscapes can have deleterious effects on pollinator communities. In particular, reduced landscape connectivity that decreases habitat patch size can have strong effects on the composition, but not abundance, of bee species assemblages in forest ecosystems (Brosi et al. 2008). Consequently, the mechanisms by which both natural and anthropogenic disturbance may influence pollinator richness and abundance in forests are complex, but critical for developing adaptive conservation strategies.

Our goal was to provide a first report of the bee fauna in a high-elevation spruce forest in the southern Rocky Mountains, with the goal of quantifying links between forest structure, understory plant species richness, and foraging bee pollinators. These links must be considered in the context of seasonal variability, as pollinator communities may shift dramatically in abundance or composition as degree days accrue—not accounting for this variability could provide reduced estimates of biodiversity or site occupancy.

Research Methods and Initial Results

Bee sampling was conducted passively using a randomized array of blue vane traps (common passive sampling traps that were co-opted from early pest management assessments when it was found that bees favored them). Overall γ-diversity (species composition among sites) in the first season of sampling was characterized by 19 genera of bees representing five families (Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae) and 39 unique species, categorized from 932 specimens (Rhoades et al. 2018). Seasonal variation in abundance and community composition was substantial and early-season (Apr) communities were dominated by *Osmia* spp. and midsummer (Jun–Jul) communities were dominated by *Bombus* spp., but bee abundance and γ-diversity were on average 88% and 74% higher midsummer than early- and late-season. It is not surprising that bumblebees were prominent in the sample; bumblebees are known to be prevalent at higher latitudes and at higher elevations, with a corresponding community shift often predicted or expected along an altitudinal gradient. Seasonal sampling further indicated a shift toward increased bumblebee dominance toward the late summer. This may be due in part to the greater thermal mass of larger bees, which may allow them to remain active even when temperatures are cool for extended periods. However, this hypothesis has not yet been tested.

Forest basal area was negatively correlated with bee γ-diversity and abundance, as well as understory plant species richness—indicating that densely vegetated forest may be inferior habitat to low-density forests. Trapping locations where basal area ranged from 7.5 m^2 ha^{-1} to 20.0 m^2 ha^{-1} exhibited ~55% higher bee abundances and ~45% higher γ-diversity than locations that exceeded 20.0 m^2 ha^{-1} basal area. Bee diversity and abundance increased with understory species richness, and species richness increased as stand basal area decreased, suggesting that forested sites with low basal area corresponded to overstory canopy gaps and increased site occupancy by flowering plants.

Management Considerations for Pollinators in Alpine Forests

With this first investigation into the bee community of forested systems, the question arises as to how alpine systems compare to other ecosystems in terms of pollinator community structure and richness. This study indicated that bee richness and diversity in nearby urban and rural areas may be higher in studies conducted by Kearns and Oliveras (2009). Community structure varied, with bumblebees being the dominant species group in alpine systems while smaller sweat bees such as members of the genera *Lasioglossum* and *Augochlorella* were dominant in urban and rural areas. The highest-richness bee communities have been noted from the arid Southwest. Bee richness within these regions often corresponded to increased spatiotemporal habitat opportunities. Forest management practices that alter forest density are likely to impact floral resources, and hence forest structural elements may be important for predicting biodiversity of wild bee assemblages. This study of pollinator diversity in alpine forests provides basal area thresholds that may be useful for resource management practitioners concerned with creating or conserving pollinator habitats. The study also provided new information on sampling efforts in high-elevation forest habitats and suggests that spatial independence of passive sampling methods may be achieved at distances of ~450 m, which may inform future studies. Additionally, this inventory provides a baseline for comparing “non-affected” spruce forests to those impacted by natural or anthropogenic disturbances in the southern Rocky Mountain region.

Although it is often assumed that pollinator density in temperate coniferous forests is low, the present study provides evidence to the contrary and indicates that alpine landscapes should not be discounted for their value to native bee conservation. With climate change, alpine systems are expected to undergo significant change (Potts et al. 2010). Beginning to assess and qualify them now provides an increased opportunity for proactive conservation efforts.

COMPETITION AND INTERACTIONS BETWEEN MANAGED HONEYBEES AND NATIVE BEES IN NORTH AMERICA

Presented by Victoria Wojcik

Can we predict the interaction between honeybees and native bees on natural lands, and how do we, as land managers, account for balancing multiple land uses? A key question has arisen in the case of support of honeybee health for agriculture, and the conservation of native bees: are honeybees outcompeting native bees for food resources in shared landscapes? Managed honeybees (*Apis mellifera*) and native bees both require nectar and pollen from flowers, and therefore, there is potential for resource-based competition between domesticated and wild bees. While concerns that introduced honeybees may limit resources for native bees are not new (Schaffer et al. 1983), recent evidence showing declines in native bee populations (e.g., Potts et al. 2010; Bartomeus et al. 2013) have intensified worries of potential impacts of competition. With the significant role that managed honeybees play in crop pollination, their health and well-being are a key concern for sustainable food production (Aizen and Harder 2009), and this has driven policy and practice aiming for access to forage. The question that is arising now is if there is cause of concern with respect to native bee populations, and if there is sufficient evidence to guide management.

In order to provide a more definitive assessment on competition between managed honeybees and native bees, researchers at Pollinator Partnership conducted a literature review focusing on studies that conducted direct tests of competition using methodologies that examined reproductive and/or population outcomes. Goals of this review were to provide evidence-based recommendations for management, pending sufficient data; determine gaps in knowledge; and outline what studies are needed to address gaps.

Evidence for Competition

With the small body of literature there was a near even split with support for the negative impacts of honeybees on wild bees seen in ten studies (Sugden and Pyke 1991; Gross 2001; Thomson 2004; Paini and Roberts 2006; Goulson and Sparrow 2009; Rogers et al. 2013; Elbgami et al. 2014; Hudewenz and Klein 2015; Herbertsson et al. 2016; Lindstrom et al. 2016) and no conclusive evidence for competition in nine (Schaffer et al. 1983; Steffan-Dewenter and Tscharntke 2000; Goulson et al. 2002; Forup and Memmott 2005; Thomson 2006; Walther-Hellwig et al. 2006; Hudenwenz and Klein 2013; Shavit et al. 2013; Torne-Noguera et al. 2016). A key point to note, and a finding outlined by some of the publications reviewed (Thomson 2006; Goulson and Sparrow 2009) is that foraging patterns do not necessarily correlate with fitness outcomes. In some cases, increased forager recruitment as a response to competition was at the expense of colony reproduction. Focusing exclusively on foraging patterns would appear as a null response to the presence of a competitor when in fact there is a negative impact.

Without actually monitoring fitness or reproduction, there is little that can be said about competition. Experiments examining reproductive consequences of competition are unfortunately the minority. Yet, six of the seven studies that examined reproductive consequence found evidence of exploitative competition with negative developmental or reproductive consequences in native bees in the presence of honeybees (Gross 2001; Thomson 2004; Paini and Roberts 2005; Goulson and Sparrow 2009; Elbgami et al. 2014; Hudewenz and Klein 2015). These included two studies of native solitary bees, and one of a native semi-social species. *Osmia bicornis* exhibited lower foraging rates and lower reproductive output in the presence of honeybees when their shared resource was limited (Hudenwenz and Klein 2015). Reduced fecundity was recorded in a tube-nesting native bee, *Hylaeus alcyones*, in the presence of managed honeybees in a natural field setting. They found that even when resources are not limited, other factors such as preemption and local exploitation can impact native bees with short foraging ranges (Paini and Roberts 2005). Colonies of *Exoneura asimillima*, a semi-social bee, were found to have significantly reduced larval number, size, and reduced pollen loads at sites where honeybees were present Sugden and Pyke (1991).

These three studies of bumblebees showed consistent trends in reduced colony growth and reproduction of native bees (lower number of queens and/or drones) in the presence of honeybees. Across these three studies, only five species of the 265 species of bumblebees have been examined; nevertheless, consistent trends in reduced growth and reproductive output were seen. The workers of *B. pascuorum*, *B. lucorum*, *B. lapidaries*, and *B. terrestris* were noted to be smaller in size in areas that had honeybee colonies present and foraging in the landscape (Goulson and Sparrow 2009); *B. occidentalis* shifted energy resource allocation to foraging in the presence of honeybees, and as a consequence produced less brood and fewer males and queens than bumblebees considered to be foraging in the absence of honeybees (Thomson 2004); another test on *Bombus terrestris* showed that colonies near honeybee apiaries gained less weight and produced fewer and smaller queens compared to those located away from honeybees (Elbgami et al. 2014).

Noncompetitive Interactions

There are other interactions that can occur between honeybees and wild bees, and with the floral community that could have impacts on community structure and composition. The foraging activities of honeybees in a landscape could alter the floral community and possibly initiate a shift in plant species dominance. This could result in a net benefit for wild bees by increasing preferred food resources, or there could be an augmentation of plant species not preferred by the native bee community. A change to local pollination networks could be expected, but the direction and impact of this change is difficult to predict and will be context specific. Pathogen spillover from one bee species to another is also a concern (Otterstatter and Thomson 2008). Common foraging resources are potential transmission vectors for pathogens, viruses, and parasites (Morkeski and Averill 2010; Blitzer et al. 2012). Pathogens can move both to wild populations from managed ones, and to managed populations from wild ones. Pathogen spillover from managed bee species is however, more commonly documented into wild populations (Graystock et al. 2013).

Managing Honeybee Pasture on Natural Lands

While research on native bee and honeybee competition was found to be very limited, there is evidence of negative interaction between honeybees and some native bees in some environments. The clearest evidence comes from negative fitness impacts seen in bumblebees, which are general feeders that have substantial potential niche overlap with honeybees. More specialized native bees, such as tube-nesting species that have much narrower niches and less direct overlap with honeybees, also showed signs of fitness decline in the presence of honeybees, suggesting in this case that they have been excluded from a portion of their narrow niche space.

The issue of maintaining honeybee colony health for pollination services while causing minimal impact to already threatened communities of native bees should be considered when putting honeybees in natural areas. There is evidence that the addition of honeybee colonies can negatively impact some native bees, particularly bumblebees and other bees that overlap in honeybee resource use. Caution therefore should be used when honeybees are put into landscapes where interactions with bumblebees are likely, especially during times of colony growth, queen development, and if local populations of bumblebees are known to be under threats or other stresses.

RESTORATION AND MANAGEMENT OF PRAIRIE HABITATS TO SUPPORT POLLINATING INSECTS

Presented by Thomas Kaye

Prairie landscapes once accounted for a significant portion of North America, but have dwindled to a small percentage of their former extent, and those that are left are highly fragmented and often relegated to tiny remnants (Noss et al. 1995). Restoring and managing prairies has therefore been a priority and our understanding of these practices has improved greatly (e.g., Krueger et al. 2014). Specific use of restoration techniques that are compatible with and support enhancement of pollinator populations is a logical next step. A restoration ecologist's tool kit includes a series of standard practices, and the impacts of each on insect pollinators varies. Mindful implementation of restoration and management practices to optimize benefits for pollinators, or minimize short term negative impacts, aids in decision making to ultimately benefit a healthy insect community.

Insect pollinators may form an ecological guild (Cane et al. 2005), but as a group they are exceptionally diverse in their taxonomy and habitat requirements. The wide variety of bees, flies, lepidopterans, beetles, and wasps that make up most floral visitors in prairies means that restored habitat must accommodate the needs of many different insects. Habitat restoration in general and prairie restoration in particular can best improve habitat for pollinating insects by increasing plant diversity for floral resources (Scherber et al. 2010), providing nesting substrates such as bare soil, cavities, and plants with pithy stems (Potts et al. 2005), and placing restoration in the setting of adjacent habitats and parcels (Artz and Waddington 2006; Cusser and Goodell 2013). For the most part, plant diversity and nesting habitat are components of the individual site, while the surrounding vegetation, its heterogeneity, and land use make up the landscape context, which may or may not be under the control of land managers at any given location.

Restoration seeding provides the fundamental groundwork for ecosystem structure and function. As such we might consider restoration and reseeding actions in the context of priming an ecosystem for pollinator function. Yet, much restoration work continues to focus heavily on quick solutions to soil stabilization and ground cover. The essential tool of restoration, the restoration seed mix, has often been designed without pollinators in mind, and often, but not always, lacks key plant species that attract key pollinators. With a focus on western prairie restoration, The Institute for Applied Ecology has produced and presented an overview of best restoration management strategies that aim to provide referenced context for technical advice. Within each common restoration strategy, there is the opportunity to adjust practices to enhance benefits to pollinators.

Prairie Restoration Treatments

Many restoration treatments may be strongly beneficial for prairie community diversity, but have short-term negative effects on pollinator populations depending on their frequency and intensity. Burning, for example, can be strongly beneficial for many prairie and grassland plant species, and the improvement in the floral community through burns aids in pollinator recolonization (Potts et al. 2005). But the intensity of a burn and depth of heat penetration can have a significant impact on some ground-nesting bee species, especially shallow nesters that are found in the top 5 cm of soil (Cane and Neff 2011). Even so, most pollinators are either unaffected by fire or recolonize burned sites after 1–3 y (Panzer 2002). Mechanical disturbance, such as mowing or haying, can have similar effects as burns and often promote bee diversity in prairie restoration (Weiner et al. 2011; Hudewenz et al. 2012). And like fire, the effects of mowing can vary with timing and frequency, location, ecosystem, and pollinator in question (Campbell et al. 2007; Smart et al. 2013; Prevéy et al. 2014). Grazing with livestock can have mixed impacts on pollinators (Kruess and Tscharntke 2002a; Kearns and Oliveras 2009; Kimoto et al. 2012). Land clearing, as defined by herbicide use, tillage, or solarization, and when followed with seeding of native plants, can have immediate, short-term negative impacts, but the benefits for pollinators can be seen in a few years after implementation, making even extreme treatments effective methods for pollinator conservation (Shuler et al. 2005; Balbuena et al. 2015).

Soil Nutrient Manipulation

Addition of nutrients to the soil can be used to boost plant growth. Most commonly this involves the addition of N and other nutrients, but generally results in increased competition for resources and a decline in plant diversity (Wedin and Tilman 1996; Suding et al. 2005), an increase in exotic invasive species that impede the success of natives (Huenneke et al. 1990; Bobbink et al. 1998), grass domination and a loss of insect-pollinated plants (Wesche et al. 2012), and reduction in pollinator resources (Burkle and Irwin 2010; Biederman et al. 2017). Therefore, fertilization to promote plant growth is not recommended for restoration of prairies or to improve conditions for pollinating insects. On the other hand, addition of C can result in nutrient depletion, and in some cases can lead to a reduction in invasive plants but also can lead to lowered diversity and productivity, and effects on different functional groups that vary by study (Blumenthal et al. 2003; Averett et al. 2004; Perry et al. 2010). The use of C addition to improve conditions for pollinators is largely untested but could have benefits in some cases, especially where soils have been enriched with N artificially.

Seed Mixes That Benefit Pollinator Diversity

Ensuring that plant species that support specialist insects are present can enhance pollinator diversity and ecosystem function. Adding species through seeding or planting plugs is necessary for increasing species richness in seed-limited prairies (Stanley et al. 2011), and therefore improving the ability of prairies to support diverse insect assemblages. Well-planned seed mixes provide sustained long-term benefits whereby plant communities are structured to include early seral species, those that protect and promote the germination of latent perennials, and overall results in a more resilient system (Williams et al. 2015; Havens and Vitt 2016).

Some insect groups specialize in visiting the flowers of specific plant taxa. The incorporation of plant species that support specialist pollinators can add diversity that might otherwise be missed with standard mixes. For example, some insects that have few body hairs are capable of handling the stringy pollen from flowers of plants in the Onagraceae, such as *Lasioglossum oenotherae*, a specialist on the pollen of evening primrose (Zayed and Packer 2007). Insects in the genus *Diadasia* (sunflower bees) often specialize on the flowers of plants in the Malvaceae, and although they may switch among specific hosts, their evolution may be driven in part by chemical or morphological traits of the plants they visit (Sipes and Tepedino 2005). Some *Andrena* (mining bees) specialize on *Nemophila* spp. (e.g., Cruden 1972). Deliberately including seeds or plugs of plants that can support local specialist insects can lead to enhanced pollinator diversity in restored prairies.

That the availability of nesting habitat for pollinators can limit their abundance in prairies and provide for enhanced nesting opportunities for multiple insect groups should be considered when planning prairie restorations. Leaving dead plant material with hollow or pithy stems during the restoration process can support nesting by leafcutter bees (*Megachile* spp.), promoting the establishment and growth of clumping grasses can provide nesting opportunities for smaller bees (e.g., *Lassioglossum*), and creating or maintaining open soil can benefit ground-nesting species (Potts et al. 2005). Many native social bees (bumblebees in particular) make use of cavities and these should be protected during restorations whenever possible.

In summary, the following are best management practices for supporting pollinators in restored prairies: (1) increase the diversity of flowering plants, (2) ensure the availability of nesting substrates, and (3) promote connectivity to adjacent habitats.

BEST MANAGEMENT PRACTICES FOR POLLINATORS: CREATING PRACTICES THAT ARE MEANINGFUL AND IMPLEMENTABLE FOR RANGELANDS ACROSS THE WEST

Presented by Scott H. Black

Rangelands comprise the majority of public lands in the western United States, spanning a huge diversity of ecological regions, habitat types, and elevations—from grasslands to sagebrush steppe to pinyon-juniper woodlands to mountain meadows. Native pollinators are an important but often overlooked group of animals that both rely upon and help maintain rangeland ecosystems. It is estimated that 40% of invertebrate pollinator species may be at risk of extinction worldwide due to stressors including habitat loss, pesticides, disease, and effects of climate change (IPBES 2016). A lack of pollinators can have major ecological and economic impacts on rangelands. Pollinators provide pollination services for flowering plants, which are fundamental components of rangeland ecosystems; approximately 85% of flowering plant species are pollinated by animals (Ollerton et al. 2011) including threatened and endangered species.

To help guide land managers on how to consider pollinators in management decisions, the Xerces Society for Invertebrate Conservation has developed two publications:

- *Best Management Practices for Pollinators on Western Rangelands*
- *Managing for Monarchs in the West: Best Management Practices for Conserving the Butterfly and its Habitat on Public Lands*

These BMPs were informed by literature reviews as well as surveys and interviews with pollinator experts and land managers. Together, they provided the state-of-the-knowledge on managing for pollinators in western rangelands. Below is an introduction to the concepts addressed in these BMPs.

What is Good Pollinator Habitat?

Food: Nectar, Pollen, and Host Plants

Providing a diverse, abundant, and season-long supply of food sources is an important component of good pollinator habitat. Provide for a wide range of flower structure, shape, color, and size as certain flowers are more attractive to some pollinator species than others (e.g., long, tubular flowers are often more attractive to butterflies and hummingbirds than to bees). Early- and late-season flowering resources can be especially important for bumblebees, which are often active in the "shoulder seasons," as well as migrating monarch butterflies. Immature butterflies feed on plant tissue and require specific host plants; some butterflies can utilize only one to a few different species of plants as caterpillars whereas other butterflies can reproduce on a wide variety of plant genera. Milkweed is vital for monarch reproduction but in the western United States it is unknown if milkweed has declined throughout the monarch's breeding range—the decline observed in the western population may be attributable to other causes.

Shelter and Nest Sites

Pollinators also need places to live and find shelter. To provide for a wide suite of pollinators leave some woody, hollow, or pithy-stemmed vegetation and ground litter intact and in place permanently. Many native bees nest below ground and require bare ground or existing cavities in which to nest. Leave some bare ground and abandoned rodent nests and preserve microtopography such as is formed by grass tussocks. Avoid mowing, burning, or grazing an entire area down to the ground. Overwintering pollinators, even adults, are generally immobile at low temperatures and unable to escape blades, flames, or livestock.

Protection from Pathogens and Competition

Managed pollinators are critical for the pollination of many agricultural crops and honey is an important industry. However, as more areas of natural habitat are converted to agricultural and suburban uses, the pressures to use public lands and other natural areas for placing honeybee hives and as a source for collecting native bees (e.g., mason bees) for commercial purposes are increasing. Managed pollinators can compete with native pollinators for resources directly or indirectly by affecting the plant community and transmitting diseases. A recent review of the literature by Mallinger et al. (2017) reported that a majority of studies identified potential negative effects of managed bees on native bees via pathogen transmission and competition. This is of particular concern for areas with declining pollinator species, including many native bumblebees.

Protection from Pesticides

In the West, management practices include the use of pesticides—which includes herbicides, insecticides, and fungicides—to remove unwanted vegetation from roadsides, control invasive weeds, and reduce outbreaks of insects that compromise rangeland productivity for livestock. Herbicides are by far the most often applied pesticide on US Forest Service lands (Cota 2004). However, insecticides such as carbaryl are sometimes used on rangelands to control grasshoppers and Mormon crickets. Pesticides can have both direct (lethal and sublethal) and indirect (harm via the effect on plants that pollinators use) effects on pollinators (Thompson 2003; Decourtye et al. 2004; Desneux et al. 2007; Kopit and Pitts-Singer 2018). It is vital to minimize the exposure of pollinators to pesticides—especially insecticides.

General Considerations in Pollinator Management and Restoration

There are thousands of native pollinator species in the West, each with unique phenologies, ranges, life history strategies, and floral and nest habitat requirements. Many species, including some bumblebees, have broad geographic ranges with varying phenologies—emerging as early as January and as late as December—and they visit a variety of flowering plants (Hatfield et al. 2012). For example, beyond milkweed as a host plant, monarch butterflies visit a variety of plants to drink nectar. For a full list of plants that monarchs use visit the Xerces Society website (https://xerces.org/monarch-nectar-plants/).

A few species of bees are extreme specialists with narrow geographic ranges, diet breadth, or phenologies that are timed with the emergence of a single plant species they visit exclusively (Minckley et al. 2013; Wilson and Messinger Carril 2015). In addition, native bee and butterfly communities and their phenology can vary widely across the landscape, such that sites even within a few miles of one another can be quite distinct (Fleishman et al. 1999; Kimoto et al. 2012; McIver and Macke 2014; DeBano t al. 2016). This dizzying diversity, and limited information in many areas, makes it impossible to prescribe a single management plan that is ideal for all pollinators in all places. However, there are general considerations that will benefit pollinators. Habitat management tools—grazing, fire, mowing, and herbicide applications—can be used to benefit pollinators and their habitat, but can also cause damage, especially in the short term. To minimize harm to pollinators, the following guidance applies to most management activities.

Create Heterogeneity in the Plant Community and Provide Refuge for Pollinators

In general, diversity in vegetation, structure, and management practices can maximize biodiversity including the diversity of pollinators (Gilgert and Vaughan 2011). To conserve the diversity of native bees that once inhabited the landscape, use and encourage plant species that benefit generalist bees, as well as species that are relied upon by specialist bees and butterflies in your region. Historically, rangeland landscapes contained sufficient areas where vegetation was in various stages of succession to support a wide range of pollinators with differing habitat needs. Today, some rangeland habitat is reduced to fragments in intensively managed or disturbed landscapes, and managers have to consider the distance and connection potential between pollinator populations (USDA USFS 2012). Mowing, burning, or intensively grazing an entire habitat area at once or in the same year, for example, can severely impact local pollinator populations and slow recolonization. It is better to treat separate areas of a site in a multi-year cycle, retaining undisturbed refuges from which pollinators can disperse. A general consideration is to treat no more than one-third of an area of continuous habitat or site (e.g., a meadow, riparian area) with a single management action (such as prescribed burning) in a single year. Even within treatment areas, leaving small untreated patches (e.g., areas skipped by mowing, fire, or grazing) provides micro-refuges and greater heterogeneity in the landscape, which can support a wider range of pollinators. With season-long grazing, try to keep at least some areas (especially sensitive areas such as springs) free from disturbance.

Consider How Management Interacts with Natural Stressors to Affect Pollinators

For example, if a drought severely suppresses wildflower blooms one season, grazing it heavily may further stress pollinators' ability to find sufficient nectar and pollen. To help minimize the effects of interacting stressors, you may need to adjust grazing pressure in years of drought. Focus efforts on conserving existing habitat that is of high value to pollinators and strive to establish plant communities that are both resilient and resistant to grazing disturbance.

Use an Adaptive Management Framework

The response of pollinators to livestock grazing and many other management practices in the West has been largely unstudied, and more research is needed to further refine rangeland management for pollinators. Given imperfect and incomplete knowledge, adaptive management using the best currently available science is necessary. Experiment on small areas, keep records, and share what works and what fails with others. Monitor vegetation and, when possible, the pollinators themselves to see how they respond to management.

Time Management to Minimize Negative Impacts on Pollinators

Timing management actions so that they occur at times when pollinators are less susceptible to harm (e.g., mobile and able to move out of the way, at a less critical developmental stage, after reproduction) significantly minimizes the likelihood of negative interactions. Seasonal patterns of pollinator occurrence and the best time to manage for bees, butterflies, and specifically monarchs, has been outlined for western regions. The BMP guide offers broad guidance on when native bees are less likely to be affected by management such as burning, grazing, or mowing. However, note that above-ground nesting bees (including some bumblebees) may be sensitive to management year-round. Management windows for monarch butterfly breeding habitat are recommended by ecoregion. Good pollinator habitat—whether it is for bees, monarchs or other butterflies—provides food, shelter, and nest sites, is connected to other habitat patches, is safe from pesticides and high levels of pathogens, and limits competition from managed pollinators. Overall, management and restoration that aims to incorporate pollinators should focus on incorporating heterogeneity into the landscape, considering interactions among management and environmental fluctuations, and using an adaptive management framework.

Management practices addressed in the Xerces BMPs include grazing, mowing, prescribed fire, and pesticide use. Incorporating pollinators into restoration projects including seeding post-wildfire and sourcing and establishing native plants are addressed, as are invasive nonnative and noxious plant management, managed pollinators, recreation, and climate change impacts.

For a complete set of Best Management Practices for both pollinators on rangelands in the West and monarch butterflies in the West, visit www.xerces.org.

NEXT STEPS: BEYOND THE SYMPOSIUM

Although such an extensive topic can hardly be examined fully in a half-day symposium, the topics presented showed that research is progressing in an effort to fine-tune best management practices across ecosystems, but also that we are not working in a void. There is a body of critical knowledge on pollinator management and conservation that can be put into action for the immediate betterment of natural landscapes and pollinators. Best practice in many cases is a precautionary best practice based on limited information, exemplified by questions of competition between managed honeybees and wild bees. The presence of honeybees appears to consistently correlate with reduced fitness in bumblebees, as well as other wild solitary bees. In cases of niche overlap and partitioned niche space honeybees are exerting an impact, and caution is warranted when making land use decisions that allow honeybee pasture on natural lands. For monarch butterflies the picture is clearer. We know where critical habitats remain, and we have identified not only the pressures that impact these areas, but clear targets for restoration. Still, monarch populations in the West have declined even more rapidly than in the rest of North America, again warranting quick action. For other pollinators occurring in the West, the data is patchy, and our management predictions may be imperfect, but we can lean on a wealth of information relating to pollinator occurrence, plant phenology, and other interactions to create solid management plans that allow for the necessary actions while minimizing negative impacts. We can reliably make evidence-based management decisions that address issues of fire, restoration, roadside management, and invasive species, all while protecting and promoting pollinators.

New research presented aiming to develop more BMPs has focused on the impact of grazing on pollinators in riparian areas and pollinator management in alpine forest communities, often considered too sparse in pollinators, yet the opposite has been shown. These are just two of many unique ecosystems that we are beginning to outline in more detail, but many more remain. How does one go forward from this point? The gaps that remain need to be filled, and it will likely be a slow process limited by access to available trained personnel and funding, certainly not by a lack of interest or urgency. This situation is nothing new to land managers and conservation biologists, and unlikely to change. The more we learn about our ecosystems the more we realize that there is much more to learn. With pollinators we are in a good place; for all that is lacking, interest and enthusiasm is not. Continued monitoring of land management actions on pollinator populations is needed. The implementation and test of current BMPs across various ecosystems is an essential strategy that will allow us to refine techniques and the guidance that we can offer. We look forward to continuing the discourse on pollinator conservation and management. Looking ahead we anticipate NAA members to present work on new ecosystems and management strategies where pollinators are the focus.

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